EFFECTS OF REINFORCEMENT MATERIALS AND MATRIX PARTICLE SIZES ON MECHANICAL PROPERTIES AND WEAR OF RECYCLED ALUMINUM CHIPS

AHMED SAHIB MAHDI

A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein onn Malaysia

May 2017

To soul of my mother and father.

To my wife Hawraa nazar and my children Mustafa, Mina and Rotaj, their love and understanding had encouraged me to complete this great opportunity in my live.

ACKNOWLEDGMENT

In the name of Allah, the Beneficent, the Merciful

I would like to express my sincerely and heartfelt thanks to Associate Professor Dr. Mohammad Sukri Mustapa for his invaluable guidance and encouragement through the course of my research work. I am very much grateful to him, for his efforts to make me and my research work worthful.

I would like to thank my co-supervisors Assoc. Prof. Dr. Mohd Warikh Abd Rashid and Dr. Abdul Latif Mohd Tobi for their guidance and advice throughout the course of this research. I also wish to thank all members in the Structural Integrity and Monitoring Research Group (SIMReG) group for their helping, suggestion and comments during in the weekly seminar progress report. I would also like to extend my sincere gratitude to Prof. Dr. Mohd Amri Lajis for always supported me in experimental and activities research works.

The study used the financial support from office for Research, Innovation, Commercialization and Consultancy Management (Short term research Grant, Vote. no. U358) and the grant from the Ministry of Science, Technology and Innovation, Malaysia, which are highly appreciated.

I also would like to extend my gratitude to the Department of Material Design and Engineering for allowing the use of the infrastructure and technical services. My sincerest appreciation is also extended to the following individuals for their invaluable contribution to this research by way of understanding and their assistance: Mr. Abu Bakar Ahmad, Mr. Fazlannuddin, Mr. Mohd Yusof and Mr. Shahrul. These people helped me during the specimen fabrication stage. I would also like to thanks Mr. Mohd. Tarmizi and Mr. Anuar for their help in conducting SEM.

I would like to acknowledgement the Ministry of higher education and scientific research, Southern Technical University, Iraq for financial support during my PhD study.

Ahmed Sahib Mahdi

ABSTRACT

Recycling is the convert operation of the waste materials into objects and new materials. The objective of this study is to recycle AA6061 aluminum from the chip. Three particle sizes were used in this study. The smaller size of particle size 25 µm was gotten. A series of studies was conducted to determine the mechanical properties, physical properties, heat treatment process, and wear resistance and to develop model prediction of wear resistance with silica reinforcement. In the first study, three particle sizes 25, 63, and 100 µm, were sieved of the milled product to characterize its bulk properties of the compression strength. Results showed that the mix of 25 and 100 µm is the best compression strength. Then, two groups were selected to study the effect of mixture particles according to the size of particles, 25 +100 µm and 25 +63 µm. Higher value of compression strength was observed by using 25 + 100 µm which was 195.6 MPa. In the second study, heat treatment of the best compound was conducted to investigate the effect of the quenching and aging processes on compression strength. The heat treatment process was implanted with the quenching temperature of 530 °C for 2 h, thus the aging temperature is 175 °C with various aging holding time. Five aging holding times, namely, 2, 4, 6, 8, and 10 h, were selected. The optimal aging holding time is 4 h, then the compression strength was 300 MPa. Finally, wear test was conducted for the milled product. Three loads were used (5, 7.5 and 10 N) and three speed were used (300, 400 and 500 rpm). Four groups were classified for the wear test. The first group was the as-fabricated milled product. The second group was obtained by optimal heat treatment. The third group used graphite as a reinforcement material. The last group used silica as a reinforcement material. The results indicated that the specimens reinforced by silica material have the highest wear resistance (105×10^{-9} g/cm) because of their high microhardness value. The prediction of volume loss was developed based on the reinforcement of silica material. In conclusion, the recycling aluminum chips process is successfully done by using 25 + 100 µm particle size reinforced by silica, the prediction volume loss, Q_{pred} was $5 * 10^{-8} \times \left(\frac{\text{L.S}}{((398.83*\%\ \text{Reinforcement})+79.22)}\right) - 0.02$.

ABSTRAK

Kitar semula adalah operasi menukar bahan buangan ke objek dan bahan baru. Objektif kajian ini adalah untuk mengitar semula aluminium AA6061 dari cip. Tiga saiz partikel digunakan dalam kajian ini. Saiz partikel yang lebih kecil 25 µm telah diperolehi. Satu siri kajian dijalankan untuk menentukan sifat mekanikal, sifat fizikal, proses rawatan haba, dan rintangan haus untuk menghasilkan ramalan model rintangan haus dengan tetulang silika. Dalam kajian pertama, tiga saiz partikel 25, 63, dan 100 µm, telah ditapis untuk mencirikan sifat pukal kekuatan mampatannya. Keputusan menunjukkan bahawa campuran 25 dan 100 µm adalah kekuatan mampatan terbaik. Kemudian, dua kumpulan dipilih untuk mengkaji kesan partikel campuran mengikut saiz partikel, 25 +100 µm dan 25 +63 µm. Nilai kekuatan mampatan yang lebih tinggi telah terhasil dengan menggunakan 25 + 100 µm iaitu 195.6 MPa. Dalam kajian kedua, hasil kompoun dari rawatan haba yang terbaik dijalankan untuk mengkaji kesan proses pelindapkejutan dan penuaan pada kekuatan mampatan. Proses rawatan haba dilakukan dengan suhu pelindap 530 °C selama 2 jam manakala suhu penuaan adalah 175 ° C dilakukan pada pelbagai masa penuaan. Lima masa pegangan untuk penuaan iaitu, 2, 4, 6, 8, dan 10 jam telah dipilih. Masa pegangan untuk penuaan yang optimum adalah 4 jam dengan kekuatan mampatan 300 MPa. Akhir sekali, ujian haus dilakukan untuk produk yang dikisar. Tiga beban 5, 7.5 dan 10 N pada kelajuan 300, 400 dan 500 rpm masing-masing digunakan didalam empat kumpulan pengujianan kehausan dilakukan. Kumpulan pertama adalah proses pengisaran, kedua diperolehi daripada rawatan haba yang optimum, ketiga menggunakan grafit sebagai bahan tetulang dan keempat menggunakan silika sebagai bahan tetulang. Keputusan menunjukkan bahawa spesimen yang diperkuat dengan bahan silika mempunyai rintangan haus tertinggi (105 × 10-9 g/cm) kerana nilai kekerasan yang tinggi. Ramalan kehilangan isi padu telah dihasilkan berdasarkan penguat bahan silika. Kesimpulannya, proses cip aluminium kitar semula berjaya dilakukan dengan menggunakan 25 + 100 µm saiz partikel yang diperkuat oleh silika dan persamalam ramalan kehilangan ramalan Q_{pred} adalah $5 * 10^{-8} \times \left(\frac{\mathrm{L.S}}{((398.83 * \%\ \mathrm{Reinforcement}) + 79.22)}\right) - 0.02$.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

a	The radius of the circular contact spots
A_p	Appearance porosity
d	Diameter
Ec	Modulus of elasticity for composit
Em	Modulus of elasticity for matrix
Ep	Modulus of elasticity for particle
G_D	Green density
Gr	Graphite powder
H	Hardness
K	constant
L	Load
m_c	Mass of composit
m_m	Mass of matrim
m_p	Mass of particle
n	Number of revolutions of the disc
n_s	The number of spots
ρ_c	Density for composite
ρ_m	Density for matrix
ρ_p	Density for particle
Q	Loss volume
r	the distance from the center of pin to the center of the disc
RT	Room Temperature
s	Distance
SEM	Scanning Electron Microscope
S_G	Specific weight
t	the time of the wear test
Tm	Melting point

v_c	Volume fraction for composite
υ_c	Poison's ratio for composite
v_m	Volume fraction for matrix
υ_m	Poison's ratio for matrix
v_p	Volume fraction for particle
υ_p	Poison's ratio for particle
w	Weight loss
W_A	Water absorption
W_d	Wight of specimen (Dry)
W_i	Wight of specimen (suspended in water)
W_r	Wear rate
W_s	Wight of specimen (saturated by water)
^oC	Degree centigrade
σ_u	Ultimate tensile strength
σ_y	Yield stress
$\%_{reinforment}$	Percentage of reinforcement particles

CHAPTER 1

INTRODUCTION

1.1 Introduction

Aluminum is the most heavily consumed non-ferrous metals in the world with the current annual consumption is 24 million tons (Hejie *et al.*, 2015). Primary aluminum (i.e., extracted from ore) is approximately 75% of this total volume (18 million tons) as opposed to that derived from scrap metal processing (i.e., secondary aluminum) (Lajis *et al.*, 2014). In every melting process of conventional aluminum recycling, many losses occur in metal oxidation and in slag mixing. Amount of the metal volume is missed by conventional recycling as a chip during the finishing process (Lajis *et al.*, 2014).

Nowadays, an economical process has been discovered instead of conventional recycling, and this process involves the direct treatment of the chip of the metal (Sung *et al.*, 2015). The method of treating and collecting metal machining waste is called metal chip processing, which uses metal crushers, oil separators, drying of the chip, and other specialized equipment. Monolithic blocks are created by the specialized equipment through cold or hot compression.

Issues in the creating environment have appeared such as wet coolant and oil, then, chips cannot be remelted efficiently and economically, and the melting loss is substantial. Subsequently, the chip processing is performed for maximum recovery and conservation (Nor azila, 2013).

Conventional recycling has caused environmental pollution. Environment protection expenditure further increases general costs (Maoling *et al.*, 2008). Several innovative processes have been proposed to recycle aluminum chip using direct hot compression (Gronostajski et al., 2000), but cold compression for aluminum recycling is suggested in the present study because of the many problems that occur during bonding between particles.

The crushing in ball mills is an important technological process applied to reduce particle size. Ball mills are also widely used for blending, mixing, and dispersing of materials, and mechanical alloying. The powder can be produced by ball milling (Ahmed *et al*., 2015a). Mixing for the matrix and reinforcement material is a critical step in powder metallurgy. This process can achieve a homogeneous distribution of particles in the matrix. Obtaining the tailored properties has become a major interest over the past three decades. Several unique mechanical properties have been derived such as high strength, high stiffness, low density, high wear resistance, and other desired properties. Nowadays, many parts used in the automobile industry, such as brake pads, pistons, gudgeon pins, cylinder liners, valves, and discs, are made from metal matrix composite materials.

Considering that the powder metallurgical method gives several advantages than other methods, it is more widely adopted in the manufacturing of metal matrix composites (MMC). The lower operating temperature in this method is an advantage as it reduces the possibility of chemical reaction between particles. It can also be mixed with several types of matrix and reinforcement phases through the same mixture system. Consequently, a higher volume fraction of reinforcement particles may be included in the compound compared to casting processes.

Composite materials are earning common acceptance as a result of their superior mechanical property, such as high strength to weight ratio.

1.2 Problem Statement

Although metal production is useful for industry, a considerable amount of waste is produced, whether material chips during turning or milling or discarded used materials. These wastes and discards come back to smelters, whereby production processes are utilized for reusing metals. During waste recycling, oxidation can result in the loss of many materials (Boin and Bertram, 2015). Labor and energy costs, along with environmental protection expenditure, increase the general cost of manufacturing (Songmene *et al*., 2011). The energy needed for recycled aluminum scrap is nearly 5% of that needed to produce it from ore. Secondary aluminum production has been greatly accepted. Various types of aluminum scrap exist, such as chips from machining or semi-finishing products. Unlike other forms of scrap, these types are difficult to recycle through conventional method (such as casting process) because of their elongated spiral shape and chip size (Amri *et al.*, 2015). The surface area is large and the apparent density is low for chips, resulting in inconvenient handling and transportation. In addition, chips are covered with oxides and emulsion oil, which are bad for recycling. Conventional recycling is characterized by a large number of operations, high operating costs, and high energy consumption.

Recently, recycled aluminum particles by milling process have been suggested as a new recycling process for machined chips because of its relatively low cost. It is also favorable for environment protection. Obtaining relatively high-density blocks from the chips is important, and these issues can be improved during solid-state recycling. The lowest energy consumption is introduced as a criterion to optimize cold compaction technology. Energy consumption during hot compaction involves endothermic and mechanical power. Hot compaction is consumed when the hydrostatic machine loosens the compacted state of the chips. Current research uses cold compaction with small particle size.

As such, the present work proposes cold compaction of small particles size aluminum chips as a method of recycled aluminum chip. Aluminum particles are mixed with other reinforcement particles to increase its wear resistance.

1.3 Objectives of Research

The objectives of this study are as follows:

a. To produce small particle sizes within range (25μm to 100μm) from recycled aluminum chip using mechanical milling.
b. To determine the mechanical and physical properties of aluminum matrix composite (MMC) produced from aluminum chips by solid state recycling.
c. To identify the effect of heat treatment on aluminum matrix composite (MMC) produced from aluminum chips.
d. To develop an empirical model based on experimental data for the wear resistance of recycled Al MMC using silica reinforcement element.

1.4 Scope of research

The scopes of this study focus on the following points:

a. Aluminum chip.
   Aluminum metal AA6061 was used in this research. High-speed milling machine (Sodick-MC 430L) at UTHM was used to produce the chip. The chip length was about 2mm from this process.
b. Preparing the specimens.
   The milling process was proceeding before the preparing of the specimen. Three speeds were used to produce small particle sizes (300, 350, 400 RPM). The duration of the milling process was 20 hrs. Particle sizes were classified to three

sizes (25, 63 and 100 µm) using sieving process. After that, each particle was mixed with zinc stearate 1 % as a binder. Cold compaction process was performed to produce the specimens in this research. Compaction pressure is carried out using uniaxial hydraulic press at the range of 5–9 tons to determine the best pressure. The holding time is within the range of 10–20 min. Sintering is performed using a tube furnace at the range 487 ºC–617 ºC to determine the best temperature.

c. Heat treatment process

Heat treatment is performed using quenching temperature at 530 ºC for 2 h and aging process at 175 ºC for 2, 4, 6, 8, and 10 h. Electrical box furnace was used for quenching and aging. The water was used as a quenching media in this research.

d. Conduct the tests

Mechanical and physical were conducted in this research. Mechanical tests are included micro-hardness, compression and wear resistance tests. Physical tests are conducted to assess density, porosity and water absorption.

e. Wear test

Pin on disc method was performed to assess the wear resistance. The pin dimensions were 13mm diameter and 10 mm height, while the dimensions of the disc were 200 mm diameter and 2 mm thickness. On the other hand, the frictional speed used for wear resistance test is at the range of 300–500 RPM, likewise the load for the wear resistance test is at the range of 5–10 N. The reinforcement materials are graphite and silica powder. The particle size of both materials is 40 µm. The percentage of reinforcement materials is 1.5%–4.5% for silica and graphite powder. Five groups were used in this test. The first was as fabricated specimen; the second was heat treated specimen, the third and fourth were reinforced by graphite and silica respectively. The last group was compound between reinforced and heat treatment process.

f. Microstructure analysis

Optical microscope is utilized to check the bonding between aluminum particles, distribution of the particles and pores. Scanning electron microscope is used to measure the length and shape of the chip size.

1.5 Contribution of the research

From this study, the following contributions have been made to the academia and knowledge. Firstly, Global reduction of carbon dioxide (emissions during casting process) is becoming important to prevent global warming caused by greenhouse production. The demand for decreasing energy consumption (fuel) of industrial processes as well as production and transportation engineering is a main factor in today's industrial world. This research introduces the direct technique of powder metallurgy with low energy consumption and cost without intervening the metallurgical processes. This technique provides low air pollution emission and high metal conservation than conventional methods. Therefore, ball mill process was used for this study to produce smaller particle size. Secondly, the compaction process is possible to accomplish at various pressing conditions. Best compaction parameters were studied. The mechanical and physical properties of recycled aluminum MMC were investigated in this study. Heat treatment process was done on the product from recycled aluminum particle sizes. Many researchers had published according to powder technology (Gaurav *at el.*, 2015; Xiao *at el.*, 2011), but the recycled material by milling process did not publish yet now. Finally, the reinforcement process is very important. Some of researchers have been used silicon carbide for reinforcement. In this study, graphite and silica were used for reinforcement. Finally, an empirical model based on experimental data was developed for the wear resistance of recycled Al MMC using silica reinforcement element as followed equation:

REFERENCES

Abdolkarim Sajjadi, Mojtaba Zebarjad, Nasrin Sasani, Heydar Khadivi, Behrooz Naderi, (2011) , Investigation and Optimization of Sn/Gr Lubricants Effects on Cold Extrudability of Fe-TiC Nanocomposite Using Taguchi Robust Design Method, *scientific research journal* , Vol . 3, pp 700-707.

Abdul R.. Abid Ali K. & Zuheir T. Khulief.Al-Tai (2010), The Effect of Iron Addition on the Dry Sliding Wear and Corrosion Behavior of Cu Al Ni Shape Memory Alloy, *Eng. & Tech. Journal*, Vol. 28, No.24.

Abdul Raheem , Zuheir T . Khulief.Al-Tai , (2012), Study the effect of silicon addition on the corrosion behavior and dry sliding wear of cu al ni shape memory alloy, *The Iraqi Journal For Mechanical And Material Engineering*, Vol.12, No.1.

Abrahim S.N., Lajis M.A., Ariffin. S. (2015), A Review on Recycling Aluminum Chips by Hot Extrusion Process, *Scince direct*, 12th Global Conference on Sustainable Manufacturing.

Adamiaka M., Fogagnolo J.B., Ruiz-Navas E.M., Dobrzañski L.A., Torralb J.M. (2004), Mechanically milled AA6061/(Ti3Al) P MMC reinforced with intermetallics – the structure and properties, *Journal of Materials Processing Technology* 155–156 (2004) 2002–2006

Ahmad Almohands ,(2010), Preparing (AL_B4C) composite material and study some of their mechanical properties, *The Iraqi Journal For Mechanical And Material Engineering*, Vol.10, No.3.

Ahmed Sahib Mahdi, Mohd Sukri Mustapa, Mohd Amri laji, Mohd Warikh Abd Rashid (2016a) “Effect of compaction pressure on mechanical properties of aluminium particle sizes aa6061 through powder metallurgical process” *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 8, April.

Ahmed Sahib Mahdi, Mohd Sukri Mustapa, Mohd Amri lajis, Mohd warikh abd Rashid (2015b), Compression Strength and Microhardness of Recycling

Milled Aluminium (AA6061) for Various Binder, *International Journal of Mechanical and Industrial Technology* ISSN 2348-7593.

Ahmed Sahib Mahdi, Mohd Sukri Mustapa,Mohd Amri lajis, Mohd warikh abd Rashid (2015c)" Effect of holding time on mechanical properties of recycling aluminium alloy aa6061 through ball mill process" *International Journal of Mechanical Engineering and Technology (IJMET),* Volume 6, Issue 9, Sep.

Akeel .A and Hanoon M.M. (2011), Effect of Silicon cavbide addition on properties of compacted Ni- Ca produced by powder technology, *Engineering and technology journal,* vol.29 , no.11 .

Akm A. I., Yoshio A., Wakako A. (2014), Fatigue crack growth mechanism in cast hybrid metal matrix composite reinforced with SiC particles and Al2O3whiskers , *science direct, Trans. Nonferrous Met. Soc.* China 24. s1−s13.

Alshmri F., Atkinson H.V., Hainsworth S.V., Haidon C,.Lawes S.D.A (2014), Dry sliding wear of aluminium-high silicon hypereutectic alloys, *Wear journal* - 313-106–116.

Ameen dwai , abbas khamas , (2008), Prepare and study the magnetic properties of compacted (Fe1-xCox), *Engineering and Technology journal* , Ver (26), No (1).

Amri L. Khamis S.S, Albert R.A.O. (2015), A Sustainable Direct Recycling of Aluminum Chip (AA6061) in Hot Press Forging Employing Response Surface Methodology, Science direct, Procedia CIRP 26, 477 – 481.

Andrei V. Kapylou, Vladimir S. Urbanovich,Rostislav A. Andrievski, Denis A. Kuznetsov, Aleksey V. Nohrin, Piotr Klimczyk (2009), Effect of compacting pressure, powder degassing and thermobaric treatment on densification and properties of nanocrystalline titanium nitride, *Processing and Application of Ceramics,*No.3,Vol.3, pp 161–166.

Andres Tominaga Terukina (2013). Barriers and solutions for closed-loop aluminium beverage can recycling. *Norwegian University of Science and Technology*, Master thesis.

Anil Kumar K. S., Anup S. Karur, Shravan Chipli, Ankith Singh (2015), Optimization of FSW Parameters to Improve the Mechanical Properties of AA2024-T351 Similar Joints Using Taguchi Method, *Journal of Mechanical Engineering and Automation,* 5(3B): 27-32.

Anna (2012), A wear test mimicking the tribological situation in rock drilling, *Teknisk- naturvetenskaplig fakultet UTH-enheten*, Sponsor: AB Sandvik Mining, Sweden.

Ashwath. P and Anthony (2014) The effect of ball milling and reinforcement percentage on sintered samples of aluminum alloy metal matrix composite, Science direct, Procedia engineering 97 – (1027- 1032).

Bhaskar H. B., Abdul Sharief (2012), Dry Sliding Wear Behaviour of Aluminium/ Be3Al2 (SiO3) 6 Composite Using Taguchi Method, *Journal of Minerals and Materials Characterization and Engineering*, 2012, 11, 679-684.

Boin U.M.J. and Bertram M. (2005) **"**Melting Standardized Aluminum Scrap:A Mass Balance Model for Europe**"** *JOM* • August.

Bolokang A. S., Phasha M. J , Motaung D. E. (2013), Ball Milling and Annealing of Co-50 at% W Powders, *International Journal of Nonferrous Metallurgy*, March ,pp 41-46.

Bryan Harris (1999), Engineering composite materials, *The Institute of Materials*, London.

Campbell F.C..(2010), Introduction to Composite Materials, *Structural Composite Materials* .

CARVALHO, R. M. 2014. Mechanistic modelling of semi-autogenous grinding. DSc Thesis, Universidade Federal do Rio de Janeiro.Universidade de São Paulo.

Ceschini L., Minak G., Morria A., Tarterini F. (2009), Forging of the AA6061/23 vol.%Al2O3p composite: Effects on microstructure and tensile properties, Materials Science and Engineering A 513–514, 176–184.

Chennakesava Reddy A. and Essa Zitoun (2010), Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites, *Indian Journal of Science and Technology*, Vol. 3 No. 12

CHIEREGATI, A. C. (2001). Novo método de caracterização tecnológica para cominuição de minérios. Dissertação (Mestrado), Escola Politécnica,

Christian K. (2012), Wear and corrosion properties of steels used in Tunnel Boring Machines, Norwegian University of Science and Technology, Department of Engineering Design and Materials, Master thesis.

Chunze Yan, LiangHao, Ahmed Hussein, PhilippeYoung, JuntongHuang, WeiZhu (2015), Microstructure and mechanical properties of aluminium alloy cellular lattice structures manufactured by direct metal laser sintering, *Materials Science & Engineering* A628 pp 238–246.

Chunze Yan, LiangHao, AhmedHussein, PhilippeYoung, JuntongHuang, WeiZhu (2015)" Microstructure and mechanical properties of aluminium alloy cellular lattice structures manufactured by direct metal laser sintering" *Materials Science&Engineering* A628, 238–246.

Corrochano J., Lieblich M., Ibáñez J.(2011)" The effect of ball milling on the microstructure of powder metallurgy aluminium matrix composites reinforced with MoSi2 intermetallic particles" *Composites: Part* A 42 ,1093–1099

Devaraju Aruri, Kumar Adepu, Kumaraswamy Adepu, Kotiveerachari Bazavada (2013)*"* Wear and mechanical properties of 6061-T6 aluminum alloy surface hybrid composites [(SiC + Gr) and (SiC + Al2O3)] fabricated by friction stir processing, jmaterres technol*;* 2(4):362–369.

Dimos Paraskevas, Kim Vanmeensel, Jef Vleugels, Wim Dewulf, Joost R. D.(2015). The use of Spark Plasma Sintering to fabricate a two-phase material from blended aluminium alloy scrap and gas atomized powder. Proceed CIRP 26, pp. 455 – 460.

Dimos Paraskevas, Kim Vanmeenselb, Jef Vleugels, Wim Dewulf, Joost R. Duflou (2015) "The use of Spark Plasma Sintering to fabricate a two-phase material from blended aluminium alloy scrap and gas atomized powder" *Procedia CIRP* 26, 455 – 460

Emile van der Heide (2002), LUBRICANT FAILURE IN SHEET METAL FORMING PROCESSES PROEFSCHRIFT, Universiteit Twente, PHd thesis.

Entsar Nife Farhaan (2009), The influence of heating temperature on corrosion resistance of high strength al- alloys 7020, Iraq, University of Technology Department of Production & Metallurgy Engineering, Msc degree Thesis.

Erlend Krogstad (2013), Degradation mechanisms due to wear and corrosion interaction of cutter tools used in Tunnel Boring Mahines, Norwegian University of Science and Technology, Department of Materials Science and Engineering, Ph. D. Thesis.

Evren T. and Bilgehan, O. (2007), Influence of Heat Treatment on the Mechanical Properties of AA6066 Alloy, *Turkish J. Eng. Env. Sci*. 31 , pp 53 – 60.

Fadhil Ateiah, Raonaq, (2010), Studying the Physical Properties of System (Al-BuC) Composite, *Engineering and technology journal* , VOL.28,NO 10.

Flores-Zamora M.I., Matinez-perez C.A. (2008), Comparative study of al-ni-mo alloys obtained by mechanical alloying in different ball mills" *Rev. Adv. Mater. Sci*. 18, 301-304.

Fogagnolo J.B., Ruiz-Navas E.M., Simón M.A., Martinez M.A. (2003), Recycling of aluminium alloy and aluminium matrix composite chips by pressing and hot extrusion, *Journal of Materials Processing Technology* pp 792–795.

Gaurav Bajpai*, Rajesh Purohit and R. S. Rana (2015), Development of Al-Nano Composites through Powder Metallurgy Process using a newly designed Cold Isostatic Compaction Chamber, Materials Today: Proceedings 2, 2737 – 2746.

Gilbert M., Petiraksakul P., and Mathieson I. (2001), Characterisation of stearate/stearic acid coated Fillers, *Materials Science and Technology* November 2001 Vol. 17 ISSN 0267 – 0836.

Gökçe A., Fındık F. (2008), Mechanical and physical properties of sintered aluminum powders, *journal of Achievements in Materials and Manufacturing Engineering,* Vol.3 issue. 2 . pp 157 – 164.

Goutam Dutta , Dipankar (2012), Effect of Sintering Temperature on Density, Porosity and Hardness of a Powder Metallurgy Component, International, *Journal of Emerging Technology and Advanced Engineering*, India, , Volume 2, Issue 8, August.

Gronostajski, W. Chmura (2000), Mechanical and Tribological Properties of Aluminum- Based Composites produced by the Recycling of Chips. Journal of Material Technology 106: 23-27.

Güley V., Ben Khalifa N., Tekkaya A. E. (2011) "The Effect of Extrusion Ratio and Material Flow on the Mechanical Properties of Aluminum Profiles Solid State Recycled from 6060 Aluminum Alloy Chips" *The 14 international ESA Form conference on material Forming AIP Conf*. Proc. 1353. 1609-1614.

Hano M .M . (2012), Effect of Zinc Addition on the Density and Wear Rate of Al-12Si Compacts, *Engineering and technology journal*, vol 30 , no 18.

Harichandran R., Selvakumar N. (2015), Effect of nano/micro B4C particles on the mechanical properties of aluminum metal matrix composites fabricated by ultrasonic cavitation-assisted solidification process, *archives of civil and mechanical engineering, ACME*-326; No. of Pages 12.

Hejie Li, Zhengyi Jiang, Dongbin Wei, Xingjian Gao, Jianzhong Xu (2015), Surface asperity evolution and microstructure analysis of Al 6061T5alloy in a quasi-static cold uniaxial planar compression (CUPC), Applied Surface Science 347, 193–201.

Höganäs AB (2004), höganäs handbook for warm compaction, Bremen, Germany,

Hubi Haleem, Newfal Zuheir, Newal Muhammad,(2012), Preparing and Studying Some Mechanical Properties of Aluminum Matrix Composite Materials Reinforced by Al2O3 particles , *Journal of Babylon University/Engineering Sciences*/ No.(1)/ Vol.(20).

Ibrahim M. Hamouda, Hagag Abd Elkader (2012), Evaluation the Mechanical Properties of Nanofilled Composite Resin Restorative Material, *Journal of Biomaterials and Nanobiotechnology*, March- 3, pp 238-242.

Ismaeel ,Raffe, Hewa (2013), The effect of heat treatment on magnetic properties for alloy (Fe-Ni) by Powder metallurgy, *Tikreet scientific journal*, No.5 , Vol. 18.

Janusz Jaglarz , Manuela Reben (2010), The influence of nanocrystallization process on thermal and optical parameter in oxyfluoride glasses, *Optica Applicata*, Vol. XL, No. 2.

Joel Fredrick Flumerfelt (1998), Aluminum powder metallurgy processing, *Iowa State University*, *Aerospace Engineering Commons, and theMetallurgy Commons.*

Kahtan Alkhazraji, Haydar Alethari, Mushtaq Albdiry,(2014)., Influence of alumina on metallographic and mechanical properties of carbide cutting inserts, *The Iraqi Journal For Mechanical And Material Engineering*, Vol.14, No1.

Kamran Azari, Houshang Alamdari, Gholamreza Aryanpour, Donald Ziegler, Donald Picard, Mario Fafard (2013), Compaction properties of carbon materials used for prebaked anodes in aluminum production plants, *Powder Technology* 246, 650–657.

Karmakar S., Rao U.R.K., Sethuramiah A. (1996), An approach towards fatigue wear modeling, *IIMMEC, IT, New Delhi* 110016, India.

Katerina Skotnicova, Miroslav Kursa, Ivo Szurman (2014), Powder Metallurgy, Faculty of Metallurgy and Materials, Technical University of Ostrava, Engineering.

Khamisa, S.S. Lajis M.A., Albert R.A.O. (2015) “A Sustainable Direct Recycling of Aluminum Chip (AA6061) in Hot Press Forging Employing Response Surface Methodology” *science direct, Procedia* CIRP 26, 477 – 481.

Kwang-Jin LEE, Eui-Pyo KWON (2014), Microstructure of stir zone in dissimilar friction stir welds of AA6061-T6 and AZ31 alloy sheets, *Trans. Nonferrous Met. Soc.* China 24- 2374−2379.

Lajis M.A., Khamis S.S., Yusuf N.K. (2014), Optimization of Hot Press Forging Parameters in Direct Recycling of Aluminium Chip (AA 6061), Metal Forming, *Key Engineering Materials Vols 622-623, pp 223-230.*

Lee S.C., Kim K.T. (2002), Densi_cation behavior of aluminum alloy powder under cold compaction, *International Journal of Mechanical Sciences* 44, 1295–1308

Linn E. (2013), Wear testing of high-alloy carbon steel used in mining Tools, Dept. of Material Science and Engineering, Royal Institute of Technology, Stockholm, Sweden, master thesis.

Luboš melúch (2009), Warm compaction of aluminium alloy alumix 123, The University of Birmingham, Department of Metallurgy and Materials, Department of Metallurgy and Materials, Ph. D. Thesis.

Manoj Singla, Deepak Dwivedi D., Lakhvir Singh, Vikas Chawla (2009), Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite, *Journal of Minerals & Materials Characterization & Engineering*, Vol. 8, No.6, pp 455-467.

Maoling H., Zesheng, J., Xiaoyu C., Zhenkao Z. (2008), Effect of chip size on mechanical property and microstructure of AZ91D magnesium alloy prepared by solid state recycling. Journal of Material Characterization, 59,385-389.

Maziar Ashur, Hossein Abdizadeh, Pooyan Tavakoli Moghadam, Arshia Nouribahadory, Hamid Reza Baharvandi (2011), Improvement in physical and mechanical properties of aluminum/zircon composites fabricated by powder metallurgy method, *Materials and Design* 32 pp 4417–4423.

Mezher A. (2015), Effect of alumina powder ddition on wear resistance of zn--4al alloy prepared by powder metallugy method, *Deiala university journal*, Vol 8, No. 3. 20-33.

Michael Oluwatosin Bodunrin, Kenneth Keneth Alaneme, Lesley Heath Chown, (2015)” Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanics, corrosion and tribological characteristics" *jmater res Technol*.

Mohammed Saeed, Sadeer Muafaq , (2009), The Mechanical Properties of Aluminum Matrix Composites, *Engineering. And Technology. journal* , ver (27), No(15).

Mohd Nazree, Zainal Arifin, Luay Bakir, Nurulakmal (2007), Study of wear on anodized PM aluminum matrix composite reinforced with 15 % saffil alumina short fiber, *International conference on sustainable materials* (ICOSM 2007).

Mohd Sukri Mustapa, Ahmed Sahib Mahdi, Mohd Amri lajis (2016)"Effect of sintering temperature on compression strength and microhardness of recycling aluminium alloy aa6061 through ball mill process*" ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 1, january.

Mohd Sukri Mustapa, Ahmed Sahib Mahdi, Mohd Amri Lajis, Mohd Warikh Abd Rashid (2015), Study Of Physical Properties Of Recycling Aluminium Chip (AA6061) On Holding Time Through Milling Process, *International Journal Of Modern Engineering Research (IJMER),* Vol. 5 | Iss. 11 | November | 47 |.

Mohd. Suhail, Mahmood Alam, Reyaz Ur Rahim (2015), The Effect of Process Parameter on Metal Matrix Composite (Al+4%Cu+5%Sic) By Stir Casting, *International Journal of Engineering Trends and Applications (IJETA) – Volume 2 Issue 1, Jan-Feb.*

Nada .S , (2011), Increased Porosity and Their Effect on The Density and Hardness Value of (Ni—Cu) Alloy , *Engineering and technology journal*, vol 29 , no 1 .

Nattaya Tosangthum, Piyanuch Muangtong,Ornmanee Coovattana, (2008) , Effects of Tin Powder on Properties of Sintered Stainless Steels , *Journal of Metals, Materials and Minerals.* Vol.18, No. 1, pp.47-51.

Nor Azila Khalid (2013), Mechanical strength of As- compacted Aluminum alloy waste chips, Universti Tun Hussein Onn Malaysia, Master thesis.

Nur Azhani Abd Razak, Juliawati A, Shah LH, and Ishak M. (2012), Effect of heat treatment on corrosion behaviour of welded AA6061 aluminium alloy in seawater, *Universiti Malaysia Pahang*, 26600 Pekan, Pahang, Omyma El-Kady A, A. Fathy (2014), Effect of SiC particle size on the physical and mechanical properties of extruded Al matrix nano-composites, Materials and Design 54 348–353.

Pardeep Sharma, Dinesh Khanduja, Satpal Sharma (2015), Parametric Study of Dry Sliding Wear of Aluminium Metal Matrix Composites by Response Surface Methodology, *Materials Today: Proceedings* 2 - 2687 – 2697.

Peter Hruby, Sudhanshu S. Singh, Jason J. Williams, Xianghui Xiao, Francesco Dearlo, Nikhilesh Chawla, (2014), Fatigue crack growth in SiC particle reinforced Al alloy matrix composites at high and low R-ratios by in situ X-ray synchrotron tomography, *International Journal of Fatigue*, Vol. 68,pp 136–143,

Poletti. C, Balog M., Simancik. F , Degischer H.P. (2010), High-temperature strength of compacted sub-micrometer aluminium powder, Acta Materialia 58, 3781–3789.

Pradeep L., Sudeep P.,Michael Nosonovsky, Satish V. Kailas, Michael R. (2013). Tribology for Scientists and Engineers. *Springer Science Business Media* New York.

Radhika N., Balaji T. V, Palaniappan.s. (2015), Studies on mechanical properties and tribological behaviour of lm25/sic/al2o3 composites, *journal of engineering science and technology,* vol. 10, no. 2 , 134 – 144

Radhika N., Subramanian R., Venkat Prasat S. (2011), Tribological Behavior of Aluminium/Alumina/Graphite Hybrid Metal Matrix Composite Using Taguchi's Techniques, *Journal of Minerals & Materials Characterization & Engineering*, Vol. 10, No.5, pp.427-443.

Radzali Othman, Azlila Zakaria (2011)" Optimisation of milling parameters during mechanical activation for direct synthesis of hydroxyapatite" *school of Materials & Mineral Resources Engineering, Universiti Sains Malaysia, Engineering Campus*, 14300 Nibong Tebal, Penang, Malaysia.

Rahimian. M, Ehsani.N, N. Parvin. N, Baharvandi. H.R (2009), The effect of sintering temperature and the amount of reinforcement on the properties of Al–Al2O3 composite, Materials and Design, 30, 3333–3337.

Rajesh S., Gopala Krishna A., Rama Murty Raju P., Duraiselvam M. (2014), Statistical Analysis of Dry Sliding Wear Behavior of Graphite Reinforced Aluminum MMCs. *Procedia Materials Science* 6- 1110 – 1120.

Randall M (1994), Powder Metallurgy Science, Second edition, German, MPIF. Metal powder.

Randoll ..German M (2001), Manipulation of Strength During Sintering as a Basis For obtaining Rapid Densification without Distortion ,*Material transaction* ,VOL.42, No.7, pp 1400 to 1410.

Reed .Razooky and Saif. M, (2013), The effect of Aluminum content on physical and mechanical properties for ceramic matrix composite , *scientificTtikreet journal* , vol.18 , no 4 .

Reshad Guluzade, Ahmet Avcı, Turan Demirci M., Faruk Erkendirci O. (2013). Fracture toughness of recycled AISI 1040 steel chip reinforced AlMg1SiCu aluminum chip composites. *Materials and Design* 52, pp.345–352.

Rikhtegar F, Shabestari S.G., Saghafian H, (2015), The homogenizing of carbon nanotube dispersion in aluminium matrix nanocomposite using flake powder metallurgy and ball milling methods, Powder Technology 280, 26–34.

Rikhtegar F., Shabestari S.G., Saghafian H. (2015)" The homogenizing of carbon nanotube dispersion in aluminium matrix nanocomposite using flake powder metallurgy and ball milling methods" *Powder Technology* 280, 26–34.

Rikhtegar F., Shabestari S.G., Saghafian H.(2015)" The homogenizing of carbon nanotube dispersion in aluminium matrix nano composite using flake powder metallurgy and ball milling methods" *Powder Technology* 280, 26–34.

Roshan M.R., Mirzaei M., Jenabali Jahromi S.A. (2013), Microstructural characteristics and tensile properties of nano-composite Al 2014/4 wt.% Al2O3 produced from machining chips, *Journal of Alloys and Compounds* 569 (2013) 111–117

Safaa Alokaidi, *(2012), F*atigue behavior of shot peened aluminum alloys under variable stress conditions, *Iraq, University of Technology, PHD Thesis.*

Salehi M., Saadatmand M., aghazadeh Mohandesi J. (2012) "Optimization of process parameters for producing AA6061/SiC nano composites by friction stir processing" *Trans. Nonferrous Met. Soc*. China 22, 1055-1063.

Sehoon Kim and Young Dokim (2011), Warm compaction of an fe-si / fe powder mixture , *Division of Materials Science and Engineering* ,Hanyang University, Seoul, Korea, pp 217 – 221.

Shaowen Lu, Ping Zhou, Tianyou Chai, and Wei Dai (2014)” Modeling and Simulation of Whole Ball Mill Grinding Plant for Integrated Control” ieee transactions on automation science and engineering, vol. 11, no. 4, october.

Song R., Ponge D., Raabe D., Kaspar R. (2005), Microstructure and crystallographic texture of an ultrafine grained C–Mn steel and their evolution during warm deformation and annealing, *Acta Materialia* 53, 845–858.

Songmene V., Khettabi R., Zaghbani I., Kouam J., and Djebara A. (2011) “Machining and Machinability of Aluminum Alloys” *Aluminium Alloys, Theory and Applications.*

Sridhar I. and Fleck N. A. (2000), Yield behavior of cold compacted composite powders, Acta mater. 48, 3341-3352.

Sumeet Mishra, Kaustubh Kulkarni, Gurao N.P. (2015), Effect of crystallographic texture on precipitation induced anisotropy in an aluminium magnesium-silicon alloy, *Materials and Design* 87 (2015) 507–519.

Sung-Mo Hong, Jin-Ju Park, Eun-Kwang Park, Kyeong-Youl Kim, Jung-Gu Lee, Min-Ku Lee, Chang-Kyu Rhee , Jin Kyu Lee (2015), Fabrication of titanium carbide nano-powders by a very high speed planetary ball milling with a help of process control agents, Powder Technology 274, 393–401.

Susniak M., Karwan-Baczewska J, Dutkiewicz,k. Pietrzak (2011), The Influence of SiC on the Properties of Aluminium Powder Obtained from Recycled Materials, *materia£y ceramiczne ,ceramic materials*/, 63, 3, 479-483.

Tadayoki Tsutsui, (2010), Resent technology of powder metallurgy and applications, *Hitachi powdered metals*,No54.

Taku Iwaoka and Mitsuru Nakamura,(2011), Effect of Compaction Temperature on Sinterability of Magnesium and Aluminum Powder Mixtures by Warm Compaction Method, *Materials Transactions*, Vol. 52, No. 5, pp. 943 to 947.

Takuji Teraoku (2008), hot isostatic pressing simulation for titanium alloys, *International journal of Powder Metallurgy*, October.

Takuya K. ,Kota K., Kazuhiko K., Koichi M. (2011), Foaming Agents for Powder Metallurgy Production of Aluminum Foam, *Materials Transactions*, Vol. 52, No. 4, pp. 728 to 733.

Tamara Aleksandrov Fabijanić, Željko Alar, Danko Ćorić (2015), Influence of consolidation process and sintering temperature on microstructure and mechanical properties of near nano- and nano-structuredWC-Co cemented carbides, Int. *Journal of Refractory Metals and Hard Materials* 54- 82–89

Umanath K., Selvamani S. T., Palanikumar K. and Sabarikreeshwaran R. (2014)" Dry Sliding Wear Behavior of AA6061-T6 Reinforced SiC and Al2O3 Particulate Hybrid Composites" *ScienceDirect, Procedia Engineering* 97,694 – 702.

Upadhyaya G. (2002), powder metallurgy technology, 1 edition , indian institute of technology, kanpur, india , cambridge international science publishing.

Verlinden. B., University of Leuven,(1994), Aluminium Powder Metallurgy, *Training in Aluminium Application Technology* (TALAT), Advanced Level 1,

Vladimir Monov, Blagoy Sokolov, Stefan Stoenchev (2012)" Grinding in Ball Mills: Modeling and Process Control" *cybernetics and information technologies*, Volume 12, No 2 Sofia.

Wen-Tien,Tsai (2013)" Microstructural Characterization of Calcite-Based Powder Materials Prepared by Planetary Ball Milling" *Materials* , *6*, 3361-3372; doi:10.3390 /ma 6083361.

XIAO Dai-hong, YUAN Tie-chui, OU Xiao-qin, HE Yue-hui (2011), Microstructure and mechanical properties of powder metallurgy Ti-Al-Mo-V-Ag alloy, Science direct, trans. Non ferrous met, China, 1269-1276.

Xing-gang Wu, Ming-zhe Yuan, Hai-bin yu "Product flow rate control in ball mill grinding process using fuzzy logic controller" Proceedings of the Eighth International Conference on Machine Learning and Cybernetics, Baoding, 12-15 July 2009.

YuanWang, Davood Rouholamin, Richard Davies, Oana R. Ghita (2015), Powder characteristics, microstructure and properties of graphite platelet reinforced Poly Ether Ether Ketone composites in High Temperature Laser Sintering (HT-LS), *Materials and Design* 88 -1310–1320.

Yukitaka Murakami, Shafiul Ferdous, Chobin Makabe,(2014), Role of Small Cracks for Discussion of Fatigue Damage in Low Cycle Fatigue of Metals, *Procedia Materials Science* 3. pp 1711 – 1716.

Zenglei Ni, Hongjian Zhao, Fuxing Ye (2015), Influence of sintering temperature on the mechanical properties and thermal expansion of SiCp/Ale30Si composites, *science* direct, Vacuum 120 -101-106.